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The role of early language experience in the development of speech perception and phonological processing abilities: evidence from 5-year-olds with histories of otitis media with effusion and low socioeconomic status

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Abstract

This study tested the hypothesis that early language experience facilitates the development of language-specific perceptual weighting strategies believed to be critical for accessing phonetic structure. In turn, that structure allows for efficient storage and retrieval of words in verbal working memory, which is necessary for sentence comprehension. Participants were forty-nine 5-year-olds, evenly distributed among four groups: those with chronic otitis media with effusion (*OME*), low socio-economic status (*low-SES*), both conditions (*both*), or neither condition (*control*). All children participated in tasks of speech perception and phonological awareness. Children in the *control* and *OME* groups participated in additional tasks examining verbal working memory, sentence comprehension, and temporal processing. The temporal-processing task tested the hypothesis that any deficits observed on the language-related tasks could be explained by temporal-processing deficits. Children in the three experimental groups demonstrated similar results to each other, but different from the *control* group for speech perception and phonological awareness. Children in the *OME* group differed from those in the *control* group on tasks involving verbal working memory and sentence comprehension, but not temporal processing. Overall these results supported the major hypothesis explored, but failed to support the hypothesis that language problems are explained to any extent by temporal-processing problems.

Learning outcomes: As a result of this activity, the participant will be able to (1) Explain the relation between language experience and the development of mature speech perception strategies,

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phonological awareness, verbal working memory, and syntactic comprehension. (2) Name at least three populations of individuals who exhibit delays in the development of mature speech perception strategies, phonological awareness, verbal working memory, and syntactic comprehension, and explain why these delays exist for each group. (3) Point out why perceptual strategies for speech are different for different languages. (4) Describe Baddeley's model [A.D. Baddeley, The development of the concept of working memory: implications and contributions of neuropsychology, in: G. Vallar, T. Shallice (Eds.), Neuropsychological Impairments of Short-term Memory, Cambridge University Press, New York, 1990, p. 54] of verbal working memory.

Keywords: Speech perception; Verbal working memory; Sentence comprehension; Phonological processing; Otitis media

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1. Introduction

For most children, language is learned through hearing. Even strict Chomskian linguists, who hold that an innate universal grammar is shaped by the ambient language, have to deal with the fact that linguistic elements, such as words and inflectional morphemes, are not easily isolated in the continuous speech stream. In brief, children are born into the world without language. Parents, grandparents, and others all speak to infants in whole phrases that do not readily reveal linguistic structure. Yet infants and young children learn to recognize words, syllables, and eventually phoneme-sized phonetic segments from the signal in order to master the syntax and grammar of their native language. Presumably this task requires a great deal of experience with the acoustic signal of one's native language. The current study tested one hypothesis about the precise role of that early experience by testing a specific prediction about what happens when the amount of experience is diminished.

Specifically this study was based on the theoretical perspective that there are optimal strategies for processing the acoustic signal of any language that allow for the recovery of linguistic structure, and these strategies are learned through early experience listening to one's native language. According to this view, experience serves to enhance the attention paid to some properties of the acoustic signal of speech, while diminishing the attention paid to others. The resulting differences in attentional (or weighting) strategies across languages have been demonstrated reliably in studies of adults' speech perception (see Strange, 1995, for a review). For example, Crowther and Mann (1994) showed that English-speaking listeners base decisions about the voicing of syllable-final stops on syllable-offset transitions and vowel duration, but Arabic-speaking listeners rely on offset transitions only. As theory suggests, Arabic does not show a vowel-duration difference for syllables with voiced and voiceless final stops (Flege & Port, 1981). Thus, native speakers of Arabic have effectively learned *not* to attend to vowel duration. Furthermore, speakers of different languages who demonstrate such differences in perceptual weighting strategies for speech signals show no complementary difference in auditory sensitivity to the properties in question. So, for example, although Japanese listeners do not pay attention to shifts in the direction or extent of third-formant transitions when labeling the lateral /l/ and retroflexed /ɹ/ of English, they are just as sensitive to changes in the direction and extent of transition when this formant is presented as an isolated glide (Miyawaki et al., 1975). Thus, it seems that these optimal perceptual strategies are tuned in each language to focus on the acoustic properties that provide the most information about phonetic structure in that language. By extension, it would benefit the child to acquire the optimal strategies for the native language being learned so that phonetic structure can easily and clearly be accessed.

Evidence that these optimal perceptual strategies are acquired over the first 7 or 8 years of life has been provided by studies investigating age-related differences in these strategies (e.g., Greenlee, 1980; Krause, 1982; Nittrouer, 1992, 2002; Nittrouer, Crowther, & Miller, 1998; Nittrouer & Miller, 1997a, 1997b; Nittrouer & Studdert-Kennedy, 1987; Parnell & Amerman, 1978; Wardrip-Fruin & Peach, 1984). Collectively these studies suggest that children initially pay attention to (or 'weight') aspects of the acoustic speech signal that provide information about large movements of the vocal tract (i.e., openings and closings), rather than information about articulatory details (e.g., exact shapes and sizes of fricative constrictions). As children get older they increasingly attend to such details. One limitation of these earlier investigations, however, has been that they could not evaluate whether these changes in perceptual strategies for speech were related primarily to general maturation (perhaps of central auditory pathways) or specifically to amount and kind of language experience. The study reported here was one of several designed to decide between these two possibilities.

The ability to access phonetic structure is critical for what it provides to other aspects of language processing. Sentences with complex syntax can be long. For these sentences, it is necessary to retain early-arriving words in memory for integration with later-arriving words. Furthermore, not only must the individual words be retained in a memory buffer, but also word order must be available for later use in syntactic analysis. Probably the most widely accepted model of verbal working memory is that of Baddeley (1990). This model consists of a central executive system, with several slave systems. One of these slave systems is an articulatory loop, used to store linguistic information in a phonetic format. To take advantage of the articulatory loop, and store information in a phonetic format (or 'code,' as it is usually termed), it stands to reason that a listener must be able to access phonetic structure in the first place. As already described, perceptual weighting strategies appropriate for one's native language are critical for accessing phonetic structure in the acoustic speech signal. The hierarchical chain of relations being suggested here (of accessing phonetic structure to storing words in verbal working memory to comprehending sentences with complex syntax) receives support from the cluster of deficits exhibited by poor readers. Difficulty in isolating and/or manipulating phonetic segments is a common finding in studies with poor readers (e.g., Pennington, Van Orden, Smith, Green, & Haith, 1990; Stanovich, Cunningham, & Cramer, 1984; Wagner & Torgesen, 1987). In addition, poor readers have shown difficulty recalling lists of words (e.g., Brady, Shankweiler, & Mann, 1983; Mann & Liberman, 1984; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979) and comprehending sentences with complex syntax (Bar-Shalom, Crain, & Shankweiler, 1993; Byrne, 1981; Smith, Macaruso, Shankweiler, & Crain, 1989; Smith, Mann, & Shankweiler, 1986). One study highlighted the connection between these skills by showing that the same group of poor readers had difficulty both accessing phonetic structure and recalling lists of words (Nittrouer & Miller, 1999).

The strongest test of the hypothesis that early language experience is associated with speech perception and related phonological processing skills would be obtained by manipulating in a controlled manner the amount of early language experience received by several groups of children with no other risk factors for language delay. Ideally, one group of children would receive enhanced language input, either through manipulation of what parents customarily provide or through clinical intervention. A second group of children would not have their environments altered, and so would receive input typical for healthy, middle-class children. A third group would have their language environments artificially constrained. However, this kind of experiment (particularly the third manipulation) cannot be conducted. Instead we must rely on alterations in language environments that occur for other reasons.

Hearing loss in children is one naturally occurring alteration that can provide a test of the proposed model of language development: Children with hearing loss are constrained in their access to the ambient language. Of course, the auditory signal that children with hearing loss receive is usually different from that of children with normal hearing, as well. Nonetheless, an earlier study (Nittrouer & Burton, 2001) was able to separate the effects of altered language experience by examining speech perception and phonological processing for two groups of children with hearing loss who differed in amount and kind of early language experience, as well as for a control group of children with normal hearing. Children in both hearing loss groups had similar types and degrees of hearing loss and were identified relatively late (mean age of identification was 3 years). All children were middle class (mid-SES) and had no major disabilities. Although no child attended a program that used sign language, the groups differed in preschool settings. Children in one group attended public school programs that enrolled children with all forms of physical, psychological, and mental disabilities. Teachers were not specifically trained to work with children with hearing loss and the curriculum was not explicitly designed to enhance language experiences. Children in the other group attended a school strictly for children with hearing loss, and the curriculum was explicitly designed to maximize language experiences. Data were collected on the four language tasks examined in the study reported here (i.e., speech perception, phonological awareness, working memory, and comprehension of sentences with complex syntax) when children were between 8 and 10 years of age. On all tasks, the group of children who attended the preschool program strictly for children with hearing loss performed comparably to children in the control group. Children who attended preschool programs for all categories of disabilities showed delays on all dependent measures. In fact their results for speech perception and phonetic awareness matched those of 8-year-olds with early histories of chronic OME or low-SES who participated in another study (Nittrouer, 1996b). In that study, children experiencing either or both of these conditions showed delays compared to a control group of children experiencing neither condition. Consequently, the combined results of these two studies, Nittrouer (1996b) and Nittrouer and Burton (2001) provide support for the suggestion that uncompensated deficits in early language experience can lead to delays in the set of language processing abilities examined in the study reported here. A study by Briscoe, Bishop, and Norbury (2001) found similar results for a group of children with mild-moderate hearing loss: Specifically children with hearing loss who performed within normal limits on standardized tests of language functioning showed phonological processing deficits commensurate with those exhibited by children with normal hearing, but with specific language impairment.

The current study was one more in the series of experiments conducted to test the proposed role of early language experience in the model of language processing outlined above. The critical difference between children in this study and children in the earlier studies of Nittrouer (1996b) and Nittrouer and Burton (2001) is the age of participants. Children in this study were all 5 years old at the time of testing and none had any formal training in reading. We tested these children just as they were about to start kindergarten. There were several reasons to use younger children in this investigation. First, the 8-year-olds in the earlier studies had had 3 years (kindergarten, first, and second grade) of explicit reading instruction. Although all children in those studies attended schools in the same public school district, and so used the same reading curriculum, it is possible that reading instruction might have interacted with whatever parents were doing at home, rendering the same instruction more effective for children from middle-class families than for those from families living in poverty. To eliminate this possible confound, we chose in this study to examine the language skills of children who had never received any formal reading instruction (i.e., 5-year-olds before entering kindergarten). Another reason to examine with younger children the same set of speech perception and phonological processing skills used in earlier studies is that the time course of the effects of early experience may vary. The deleterious effects of deficits in early experience may fade away (i.e., children might "catch up"), or effects may become apparent only at later ages as children who received appropriate experience pull ahead of children who did not. Roberts, Burchinal, Koch, Footo, and Henderson (1988) provide an example of this latter situation in their examination of phonological processes exhibited by children between $2\frac{1}{2}$ and 8 years of age with and without histories of chronic OME. During the preschool years (i.e., up to age $4\frac{1}{2}$), no differences were observed between these groups. However, during the early school years, phonological processes "dropped out" faster for children without histories of chronic OME than for children with histories of OME.

In summary, the study reported here tested a specific hypothesis concerning the role of early language experience by examining a set of skills in 5-year-old children presumed to have deficits in early language experience: children with histories of early, chronic OME and children growing up in conditions of low SES. In addition, children experiencing both of these conditions were included in the study to see whether the effects (if any) of these conditions are redundant, summed, or confounded. Nittrouer (1996b) reported no differences in performance on speech perception and phonological awareness tasks for children living in low-SES environments and children experiencing both low-SES and early, chronic OME, and we wanted to see if this result would be obtained for younger children. Specifically, the study was designed to examine whether the perceptual weighting strategies of children in these three groups appeared developmentally delayed compared to peers with no experiential deficits. Also we planned to examine whether access to phonological structure in the acoustic speech signal is constrained for children in these groups. Thirdly, the hypothesis was tested that diminished access to phonological structure would negatively impact children's abilities to store linguistic materials in working memory, and so to comprehend sentences with complex syntax. Finally, an alternative to the hypothesis offered here was tested. A popular notion currently is that children with phonological processing (and other language problems) do not suffer from linguistic deficits at all, but instead have problems processing rapidly arriving signals (i.e., 'temporal-processing' deficits). Because these children cannot properly process rapidly arriving signals, the theory holds, they are unable to make use of formant transitions, and so cannot recognize consonant identity (e.g., Tallal, 1980; Tallal & Piercy, 1974, 1975; Tallal et al., 1996). Of pertinence to this study, one of the few suggested roots for the hypothesized temporal-processing problem is the presence of early, chronic OME (Merzenich et al., 1996).

There is good reason to suspect that children with both early, chronic OME and low-SES experience diminished language input as infants and/or young children. Children with histories of early, chronic OME experience periods of raised auditory thresholds that may last months, often even with ventilation tubes in place (Fria, Cantekin, & Eichler, 1985; Friel-Patti, 1990; Friel-Patti, Finitzo-Hieber, Conti, & Brown, 1982; Gravel & Wallace, 1995, 2000; Rovers et al., 2001; US Department of Health and Human Services, 1994). It is presumed that these fluctuating hearing losses can interfere with the amount and quality of language input. Numerous reports find that children with these histories show delays on general measures of speech and language development (e.g., Friel-Patti & Finitzo, 1990; Nittrouer, 1996b; Teele, Klein, Rosner, & The Greater Boston Otitis Media Study Group, 1984; Updike & Thornburg, 1992), and several studies find that these children have specific difficulty categorizing acoustic speech stimuli (Eimas & Clarkson, 1986; Gravel & Wallace, 1992; Nittrouer, 1996b). Regarding children in low-SES environments, numerous studies report that the amount of parental language input to these children is commonly diminished, compared with what children in mid-SES environments receive, and that the form of that language input differs (e.g., Hart & Risley, 1995; Honig, 1982; Laosa, 1982; Schachter, 1979; Walker, Greenwood, Hart, & Carta, 1994). This difference in input was examined for children participating in Nittrouer (1996b), and results were reported in Nittrouer (2002). As part of the experimental protocol for the Nittrouer (1996b) study, parent–child dyads worked to make a Tinkertoy model from a picture, and each parent–child dyad was videotaped for 10 min. Examiners who were blind to SES status scored parental language behaviors using an interval-scoring procedure (with 10-s observation intervals and 2-s recording intervals). During a 10-min session, parents in the low-SES dyads typically talked to their children less (52 parental language acts versus 64 for both control and OME dyads). In particular, fewer of these parental language acts were inquiries (7% for the low-SES parents versus 19% for mid-SES parents and 15% for parents of children with OME histories).

As a result of the numerous reports cited above, these two populations of children (those with histories of early, chronic OME or low-SES) were presumed to have had diminished early language experiences. Of course, it is always possible that an unanticipated (and so uncontrolled) difference between either of these groups and children in the *control* group could exist that would explain any observed difference on one of the dependent measures, and it is precisely because of this possibility that we included children from both populations in data collection. In the absence of the ability to experimentally control early language experience, including children believed to have suffered deficits in early experience for different reasons adds strength to the hypothesis being tested.

2. Method

2.1. Participants

Children between 59 and 71 months (4 years, 11 months and 5 years, 11 months) were recruited by distributing flyers through the local schools. The numbers of boys and girls in each group were kept fairly equal (i.e., no more than a 60/40 split). To participate, children needed to meet several criteria. They needed to pass a hearing screening, consisting of puretones of the frequencies 0.5, 1.0, 2.0, 4.0, and 6.0 kHz, presented at 25 dB HL (American National Standards Institute, 1989). They needed to have normal tympanograms at the time of testing. They needed to score at or above the 20th percentile on the Goldman–Fristoe Test of Articulation (Goldman & Fristoe, 1986), and produce acceptable versions of /s/ and /ʃ/. They needed to score at or above a standard score of 70 on the Peabody Picture Vocabulary Test-III (PPVT-III) (Dunn & Dunn, 1997). The Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence—Revised (WPPSI-R) (Wechsler, 1989) was used to obtain an estimate of nonverbal reasoning. This subtest has a mean of 10 and a standard deviation (S.D.) of 3 (i.e., it uses scaled scores). To participate, a child needed to demonstrate a score of at least 7. However, we did not obtain scores on the Block Design subtest for children in the *low-SES* group because it was apparent from our piloting efforts that we would have difficulty getting children in the *low-SES* and *both* groups to come to the laboratory more than once. Consequently we pared down our protocol for those groups, ensuring that we collected data on one speech perception and two phonological awareness tasks the first day. Fortunately, all children in the *both* group did return for one additional session, and so we administered the Block Design subtest at that time. All children in this group easily exceeded the criterion, and there is no reason to suspect that children in the *low-SES* group would have fared less well.

SES was coded as it had been in Nittrouer (1996b), using a scheme derived from Hollingshead (1965) and Laosa (1982), but with occupations updated to reflect the influence of technology on the labor market. Occupational status and educational level of the primary income earner in the home (or, ‘household head’) were used to obtain an SES metric for the household. Hauser (1994) suggests that characterizing the household in this way, rather than by focusing on father’s or mother’s characteristics alone, provides a more valid indicator of family SES. Two eight-point scales were used, with “8” representing both the highest occupational status and the highest educational level (see Appendix A). Derived codes for occupation and education were multiplied to obtain SES metrics, and so scores varied from 1 to 64. Because codes are multiplied to obtain an SES metric, the resulting scale is not linear: that is, equivalent differences on one of the scales will result in unequal differences in SES depending on whether it is at the lower or higher end of the scale. For example, if two individuals receive educational codes of 2 but one receives an occupational code of 1 and the other receives an occupational code of 2, they will obtain SES metrics of 2 and 4, respectively. However, if two individuals receive educational codes of 8, but one receives an occupational code of 7 and the other receives an occupational code of 8, they will obtain SES metrics of 56 and 64, respectively. Thus, a one-point difference on either of the scales results in a two-point difference in SES at the lower end of the scale, but an eight-point difference at the higher end.

Hauser (1994) further suggests that estimates of household SES based on occupational and educational indices alone do not adequately characterize the social and economic environment of the home. He concludes that such metrics must be considered in conjunction with economic level. Therefore, data were collected about annual family income, and was coded using a five-point scale: (1) less than $15,000; (2) between $15,000 and $25,000; (3) between $25,000 and $40,000; (4) between $40,000 and $60,000; and (5) greater than $60,000.

Histories of OME were derived by examining children's medical records. Parents granted permission to have their medical records sent to the Speech Perception Laboratory. These records were perused for diagnoses of OME. A discrete episode of OME was one in which a diagnosis was made more than 30 days after another episode. Children were considered to have positive OME histories if they had 7 or more documented episodes of OME before the age of 3 years. This criterion meant that children in the *OME* group had effusion present for at least 20% of their lifetime, but likely longer. The exact amount of time spent with effusion would have varied depending on numbers of discrete OME episodes and duration of effusion. Children were considered to have negative OME histories if they had 3 or less documented episodes of OME before the age of 3 years.

To be placed in the *control* group, a child needed to have an annual family income of at least $25,000, an SES score of at least 25, and a negative history of OME. To be placed in the *OME* group, a child needed to have an annual family income of at least $25,000, an SES score of at least 25, and a positive history of OME. To be placed in the *low-SES* group, a child needed to have an annual family income of less than $15,000 for families of four or less and less than $25,000 for families of five or more, an SES score of less than 15, and a negative history of OME. To be placed in the *both* group, a child needed to have an annual family income of less than $15,000 for families of four or less and less than $25,000 for families of five or more, an SES score of less than 15, and a positive history of OME.

Table 1 displays demographic information on the 49 children who participated in this study. Results for occupational index, educational index, and SES show that children in the

Table 1
Mean demographic information about participants in each group, with standard deviations in parentheses

	Control (12)	OME (13)	Low-SES (12)	Both (12)
Age (months)	65.7 (3.4)	64.8 (3.6)	63.4 (3.4)	64.6 (4.7)
Annual family income	3.83 (.72)	4.23 (.83)	1.25 (.45)	1.25 (.45)
Occupational index of primary income earner	5.75 (.62)	5.23 (.93)	2.64 (.92)	1.67 (1.07)
Educational index of primary income earner	6.46 (.99)	5.81 (.63)	3.36 (.39)	2.79 (.62)
Socio-economic status	37.4 (8.7)	30.3 (6.3)	8.9 (3.4)	4.8 (3.7)
Number of ear infections, before age 3 years	0.7 (1.1)	10.4 (2.6)	0.4 (0.7)	9.4 (2.6)
Goldman–Fristoe percentile	79.0 (22.3)	56.1 (28.5)	79.0 (24.3)	66.0 (33.7)
PPVT-III standard score	111.9 (10.3)	107.7 (9.6)	96.3 (11.1)	85.5 (14.2)
WPPSI-R Block Design scaled score	11.4 (2.2)	11.2 (2.4)	–	10.7 (1.8)

The number of children in each group is given under the group heading. See text for details about each screening measure.

control and *OME* groups came from homes where the primary income earners tended to have college educations (or at least some college) and worked in professional jobs. Children in the *low-SES* and *both* groups tended to come from homes where the primary income earners had not attended university at all and may not have completed high school. The primary income earners in these homes either did not work or worked in service jobs such as waiting tables or cleaning homes. Children in the *control* and *OME* groups came from homes in which the annual income was generally greater than $40,000. Children in the *low-SES* and *both* groups came from homes in which annual family incomes were less than $15,000, except for six children whose family incomes were between $15,000 and $25,000. These children all had six or more family members living on that income. All children in the *control* and *OME* groups had both parents living in the home. Two children in each of the *low-SES* and *both* groups had two parents in the home; the rest were living with only their mothers.

2.2. Equipment

All testing took place in a sound-attenuated booth. The hearing screenings and tympanograms were obtained with a Welch Allyn TM262 audiometer/tympanometer with TDH-39 earphones. For the phonological awareness and sentence comprehension tasks, recorded stimuli were used. These stimuli were presented with a Nakamichi MR-2 audiocassette player, a Tascam PA-30B amplifier, and a Realistic speaker. For the speech perception, verbal working memory, and nonspeech temporal-processing tasks, digitized stimuli were used. These stimuli were presented using software specifically written for each task. Stimuli were stored on a computer, and presented with a Data Translation 2801A digital-to-analog converter, a Frequency Devices 901F analog filter, a Crown D-75 amplifier, and AKG 141 earphones. At the end of each block (in speech perception) or stimulus set (in the other tasks), children were presented with cartoon characters drawn on a color-graphics monitor as a way of maintaining their attention. For all tasks, stimuli were presented at a peak intensity of 70 dB SPL.

2.3. Materials and specific procedures

All screening tasks were administered first, followed by the eight tasks for the dependent measures: two sets of speech perception materials, three sets of materials for phonological awareness, one verbal working memory task, one sentence comprehension task, and one task examining temporal-processing abilities. All materials have been used in earlier experiments (Nittrouer, 1996b, 1999; Nittrouer & Burton, 2001; Nittrouer & Miller, 1999). Because we could count on children in the *low-SES* and *both* groups to attend only one session, they were tested only on one speech perception task (fricative-vowel syllables) and two phonological awareness tasks (one of syllabic awareness and one of phonetic awareness). All children in the *control* and *OME* groups were tested with all eight sets of materials over three days. By having data from all children for a speech perception task and two phonological awareness tasks, we were able to further our understanding of the role of early language experience on the development of these two abilities. By having data from at least two groups (one control and one with a presumed deficit in early language experience), we were able to make suggestions about relations among the set of skills examined. Finally, we obtained a measure of parental language input on the 3 days of testing for children in the *control* and *OME* groups.

2.4. Speech perception

Two speech perception tasks were used. For each task, a different set of stimuli were developed such that one acoustic property varied along a continuum from a setting appropriate for one phonetic category to a setting appropriate for another phonetic category. A second acoustic property differed across just two settings, each appropriate for one or the other phonetic category. All stimuli were generated at a 10-kHz sampling rate, and presented with low-pass filtering below 4.8 kHz. All stimuli were presented 10 times each. A two-alternative forced-choice labeling procedure was used in which participants responded by pointing to a picture (5 in. × 5 in.) of the label chosen and saying the response. Cumulative distributions of the percentage of responses given for one of the phonetic categories (i.e., labeling functions) were obtained, at each level of the dichotomously set property. Probit transformations (Finney, 1964) were then used to obtain a distribution mean (i.e., the point where the labeling function crosses the 50% line, known as the 'phoneme boundary') and a slope (i.e., rate of change on the y-axis per unit of change on the x-axis). These scores index the perceptual attention (or weight) assigned to each property. Slope serves as a general index of the perceptual weight given to the continuous property (i.e., the one represented on the abscissa). In general, the steeper the function, the greater the weight that was given to that property. The separation between functions, usually measured at the phoneme boundaries, indexes the weight given to the non-continuous property.

For both sets of stimuli the same kinds of pre-test experiences were provided. First, children heard stories about the pictures used to represent category labels (always animate objects). For example, 'sa' was a juvenile space alien who one day made a trip to earth with her family. These stories were presented via audiotape, first with a real (taped) speaker, and then with synthesized speech. Children were asked questions about each story to make sure that they had listened to and comprehended the story. Next children were required to respond to 10 digitized, natural tokens of the stimuli with 90% accuracy. Then they had to respond to 10 tokens of the best category exemplars of the created stimuli (i.e., the stimuli for which both acoustic properties most clearly indicated one label or the other), again with 90% accuracy. If a child failed to meet the 90% correct criterion on either training set the test stimuli were not presented. Finally, the child's data had to show at least 80% correct responses to the best category exemplars to be included in the analysis.

2.4.1. Fricative-vowel

All children were tested with these stimuli. These stimuli have been used frequently in the past (Nittrouer, 1992, 1996b, 1999; Nittrouer & Burton, 2001; Nittrouer & Miller, 1997b), and were selected for this study because these specific stimuli, as well as other, similar fricative-vowel stimuli, have robustly demonstrated developmental changes in perceptual weighting strategies for speech (Nittrouer, 1992, 1996a; Nittrouer & Miller, 1997a, 1997b; Nittrouer & Studdert-Kennedy, 1987). Specifically, young children weight formant transitions more and fricative-noise spectra less than adults in making judgments of whether an initial fricative is /s/ or /ʃ/. As they get older this developmental strategy shifts so that noise is weighted more and formant transitions less. Using these stimuli, some studies showed delays in these developmental weighting shifts for 8-year-olds who experienced conditions presumed to interfere with early language input (Nittrouer, 1996b), in 8- to 10-year-olds with phonological processing problems (Nittrouer, 1999), and in 8- to 10-year-olds with hearing loss who attended preschools for children with a variety of disabilities (Nittrouer & Burton, 2001). Thus, these stimuli seemed ideally suited for revealing delays (if any) in the development of mature weighting strategies for 5-year-olds with histories of early, chronic OME, low-SES, or both conditions.

These stimuli were hybrids consisting of synthetic fricative noises concatenated with natural vocalic portions that have onset transitions appropriate for either a syllable-initial /ʃ/ or /s/. The nine fricative noises were 150 ms long, with a single pole varying in center frequency between 2.2 and 3.8 kHz, in 200-Hz steps. The natural vocalic portions were taken from a male speaker saying /ʃɑ/, /sɑ/, /ʃu/, or /su/. Each vocalic portion used in the study was separated from the natural fricative noise of the syllable, and recombined with each of the nine synthetic noises. Because each vowel context (/ɑ/ or /u/) was presented separately, there were 18 syllables per set (nine fricative noises × two transition conditions).

2.4.2. Voice onset time (VOT)

Only children in the *control* and *OME* groups were tested with these stimuli. In developmental studies, it is good to have demonstrations that participants across groups perform similarly for some stimuli using methods that demonstrate group differences for other stimuli. These demonstrations reassure us that any observed group differences are real, and not simply the result of variation among groups in abilities to perform the task. Nittrouer (1999) showed that even children with poor phonological processing abilities were able to label syllables varying along a VOT continuum, and so these stimuli seemed ideally suited to testing task demands across groups in this study.

Synthetic vocalic portions were 270 ms long, with a 40-ms first-formant (F1) transition at the beginning. During this transition, F1 changed from its starting frequency of 200 Hz to its steady-state frequency of 650 Hz. The second and third formants (F2 and F3) changed over the first 70 ms of the vocalic portions. F2 started at 1800 Hz, and fell to its steady-state frequency of 1130 Hz. F3 started at 3000 Hz, and fell to its steady-state frequency of 2500 Hz. The fundamental frequency was constant at 120 Hz for the first 70 ms, and then fell linearly through the rest of the vocalic portion to an ending frequency of 100 Hz. A nine-step continuum was created by cutting back the onset of voicing in 5-ms steps from 0 to 40 ms. Before voicing started, no source excited F1, but aspiration noise excited the higher formants. Each of these nine portions was concatenated with each of two natural 10-ms bursts: one from a male speaker saying /dɑ/ and one from the same speaker saying /tɑ/. Thus there were 18 of these stimuli: nine VOTs × two bursts.

2.5. Phonological awareness

Three phonological awareness tasks were used. In each, the number of correct responses served as the dependent measure. Children in all four groups were tested on the 'syllable counting' and 'same-different' tasks described below. Only children in the *control* and *OME* groups were tested on the 'three-choice initial-consonant-the-same' task. These tasks, as well as practice items, were presented via audiotape, and so procedures were standardized.

2.5.1. Syllable counting

In this task, participants tapped out the number of syllables in each word. It used the first 23 items in the syllable counting task of Liberman, Shankweiler, Fischer, and Carter (1974), plus the word 'boat' (also found in the list used by Liberman et al.). There were equal numbers of one-, two-, and three-syllable words. Five items were presented with live-voice for practice: the participant's name, the name of a sibling or pet, and the words *cat*, *catnap*, and *catnapping*. It was followed by 12 practice words on tape. These words were: *but*, *butter*, *butterfly*, *tell*, *telling*, *telephone*, *doll*, *dolly*, *lollipop*, *top*, *water*, *elephant*.

This task was the easiest phonological awareness task used in this study. Results from others (e.g., Fox & Routh, 1975; Liberman et al., 1974) indicate that children are able to recognize and manipulate word-internal syllable structure before they are able to recognize and manipulate syllable-internal phonetic structure. Consequently, it was not unreasonable to suspect that all children in this study may have been able to perform this task quite well, regardless of group. Thus, this task was included as a control condition to demonstrate that all children in the study were able to demonstrate their awareness of linguistic structure, when such awareness was present.

2.5.2. Three-choice initial-consonant-the-same (ICTS) task

This 24-item task is commonly used to measure awareness of word-initial segments for 5-year-olds (Stanovich et al., 1984). A target word is presented first, followed by three other words. The child must say which of the three words has the same 'sound' at the beginning of the word as the target word. The items for this task can also be found in Nittrouer (1999).

2.5.3. Same-different ICTS task

This task was developed due to concern that some 5-year-olds might have difficulty retaining four words in working memory. In this task, two words were presented and the participant reported whether the 'sounds' at the beginnings of those words were the "same" or "not-the-same." There were 48 word pairs, and 24 of these word pairs had the same initial consonant. Items are shown in Appendix B. Six practice items were used.

2.6. Verbal working memory

This task was used by Nittrouer (1999) and by Nittrouer and Miller (1999), except the lists were longer in those earlier studies, as was appropriate for the 8- to 11-year-olds who participated. In this study, lists of three and four words, both rhyming and nonrhyming, were used. The three-word rhyming lists consisted of the words *hat*, *cat*, and *bat*. The three-word nonrhyming lists consisted of the words *ball*, *coat*, and *dog*. The words *rat* and *rake* were added to the rhyming and nonrhyming lists, respectively, to make four-word lists. The words were digitized, and presented via computer at the rate of one per second. The child's task was to rearrange pictures (2 in. × 2 in.) in the order in which the words were heard (left-to-right arrangement). A computer program controlled the order of presentation of the words, and a new order was generated on-line with each presentation. Each participant heard 10 lists of each kind. The order of presentation of kinds of lists was the same for all participants: three-word nonrhyming, three-word rhyming, four-word rhyming, and four-word nonrhyming. The number of errors served as the dependent measure.

Before testing, several steps were taken to ensure that the participants' scores were dependent only on recall of word order. First, the experimenter showed the child how to arrange pictures going from left-to-right, and then handed the pictures to the child one at a time and asked that they be placed in the correct order. Next 10 three-word, nonrhyming practice lists consisting of the words *ham*, *pack*, and *seed* were presented. For the first five practice lists, the experimenter demonstrated the task; for the last five, the child performed the task, with feedback. Before testing with any set of pictures, the experimenter told the child the name of each picture and laid each on the table. The experimenter then asked the child to point to the proper picture in response to the word heard (spoken live voice).

2.7. Comprehension of complex syntax

The 25 sentences used in this task were the same as those used by Nittrouer (1999). These sentences all described the actions of two animate objects, involved one inanimate object, and could be 'acted out' easily by young children with small toys. The sentences were arranged in five sets of five each. Four of the five sentences in each set were constructed with relative clauses. These sentences were classified by two-letter codes ("S" for subject and "O" for object), with each letter indicating the role that the noun phrase occupying the "empty" position of the relative clause served in the main clause (first letter) and in the relative clause (second letter). For example, the code SS indicates that the noun phrase *the bear* was the subject of both the main clause and of the relative clause in the sentence "The bear who wore a hat chased the dog." The fifth sentence in each set consisted of two conjoined clauses (CC) such as "The dog chased the bear and wore a hat." Sentences were presented via audiotape, and the number of errors served as the dependent measure.

One set of practice sentences was provided before testing. Also, the small toys used with each set of sentences were introduced before testing with that set. The experimenter said the name of each toy in turn and put it on the table. The child was then asked to point to each toy as its name was said. Finally, two practice sentences with no relative or conjoined clauses were included at the beginning of each new sentence set to give the child practice acting out sentences.

2.8. Nonspeech temporal processing

This task was used by Nittrouer (1999) to test the hypothesis that temporal-processing deficits cause phonological processing problems. The task used two sinusoids, both 75 ms long. One was 800 Hz and the other was 1200 Hz. Procedures for the task were based on those of Tallal (1980). A board (24 in. × 8 in.) with two large, colored buttons on it was used for recording children's responses directly to the computer. This board had a handle on either end that children were instructed to hold when not responding.

The first step in this task was that the child became familiar with each tone by pressing each button 10 times in a row. Each time a button was pressed, the tone associated with that button was played. Next the two tones were presented one at a time in random order, and the child had to press the button corresponding to the tone heard. The tone was played again after the button was pressed, to reinforce correct responding. After six consecutive correct responses at this training step, the program moved to the next training step. If this criterion was not achieved within 20 trials, the task was stopped. In the next step, tones were again presented one at a time in random order, but the tones were no longer played after the buttons were pressed. Again, the child had to provide six consecutive correct responses (within 20 trials) to move to the third, and final, training step. In this training step, two tones were presented sequentially, with an interstimulus interval (ISI) of 320 ms. The child's task was to replicate the order of presentation of the tones with button presses. When the child had provided six consecutive correct responses (out of 20 trials), testing started. During testing, 10 trials at each level of sequence number × ISI were presented, and the number of errors recorded by the program. The first level of testing consisted of two-tone sequences, with 320-ms ISIs. The ISI was halved at each subsequent level, until it was 20 ms. Then, three-tone sequences were presented, starting with a 320-ms ISI. Finally, four-tone sequences were presented, again starting with a 320-ms ISI. Thus, there were 15 levels of testing: three sequence lengths (2, 3, and 4 tones) × 5 ISIs (320, 160, 80, 40, and 20 ms).

Not all children were tested at all 15 levels. If a child made seven errors at one level of testing, the program immediately went to the next sequence length, starting at the longest ISI (320 ms). Testing never progressed to an ISI briefer than the one on which the child made the seven errors, at any sequence length. For example, if a child failed to replicate the order of presentation for seven trials of the two-tone sequence at the 40-ms ISI, the program jumped to the three-tone sequence next. Then, it did not present stimuli with a 40- or 20-ms ISI, for either the three- or four-tone sequences. For these conditions, the child was given scores of 10 errors (the maximum). This procedure would not have diminished the chances of obtaining group differences, if such differences existed. In fact, quite the opposite. The hypothesis being tested was that the children with poorer phonological processing abilities (children in the *OME* group in this study) would be poorer at recalling the order of tone presentation, *for brief ISIs*. Accordingly, these are the very children who would be predicted to encounter the situation where they were not tested at brief ISIs. Because 10 errors were assumed at each level of testing not presented, and those levels were the very conditions with brief ISIs, the procedure only biased results towards finding differences between children in the *control* and *OME* groups. However, the important consideration is that by not forcing these young children to participate in conditions in which they were certain to fail their overall attention to the task was maintained better than it would have been otherwise. Tallal (1980) reported that 4 years of age was the absolute youngest that she was able to get a child to do this generally difficult perceptual task. Consequently, it is fair to say that we were asking a lot of 5-year-olds to begin with.

2.9. Tinkertoy task

In addition to the above tasks, children in the *control* and *OME* groups worked with one of their parents to make a Tinkertoy model. These sessions were recorded and subsequently coded for parental language acts using procedures described in Nittrouer (2002).

3. Results

3.1. Tinkertoy task

The total numbers of parental language acts during the 10-min recording sessions were 82 (S.D. = 19) for *control* dyads and 83 (S.D. = 16) for *OME* dyads. The percentages of these language acts that were inquiries were 22 (S.D. = 6) for *control* dyads and 21 (S.D. = 7) for *OME* dyads. These results provide evidence (in addition to similar SES scores and incomes) that the language environments of children in the *control* and *OME* groups were similar. Therefore, any differences observed between these two groups may be attributed to disruptions on the part of children in the *OME* group in fully accessing the language in their environment.

3.2. Speech perception

3.2.1. Fricative-vowel

Six of the children in the *both* group, two children in the *low-SES* group, and one child in the *OME* group were unable to label natural tokens of /ʃ/-vowel and /s/-vowel, for both /ɑ/ and /u/. No child who was able to label natural tokens of /ʃ/-vowel and /s/-vowel was subsequently unable to do so with the hybrid tokens, and so we conclude that the synthetic nature of the fricative noises did not create particular problems for these children. Because only half the children in the *both* group were able to label natural tokens, data for that group were not included in the final analysis: When only half the group can perform the task, it would not be appropriate to suggest that they are representative of that population. Besides, the six participants in the *both* group who did participate had results suggesting that even they had great difficulty using either acoustic property to make phonetic judgments. On average, their functions were shallower than for any other group and hovered near the 50% line. In general, they just barely obtained the 80% correct recognition for best exemplars required to have data included in the analysis.

Fig. 1 displays mean labeling functions for children in the *control*, *OME*, and *low-SES* groups, and suggests that children in the *OME* and *low-SES* groups based their responses more on formant transitions and less on fricative-noise spectra than children in the *control* group: Children in the *OME* and *low-SES* groups did not give more than 75% ‘s’ responses to stimuli with /ʃ/ formant transitions, even when those stimuli had the most /ʃ/-like noise (3.8 kHz), and did not give fewer than 25% ‘s’ responses to stimuli with /s/ transitions, even when the stimuli had the most /ʃ/-like noise (2.2 kHz). Children in the *control* group gave close to 100% ‘s’ responses to stimuli with the most /s/-like noise, and close to 0% ‘s’ responses to stimuli with the most /ʃ/-like noises, regardless of transitions.

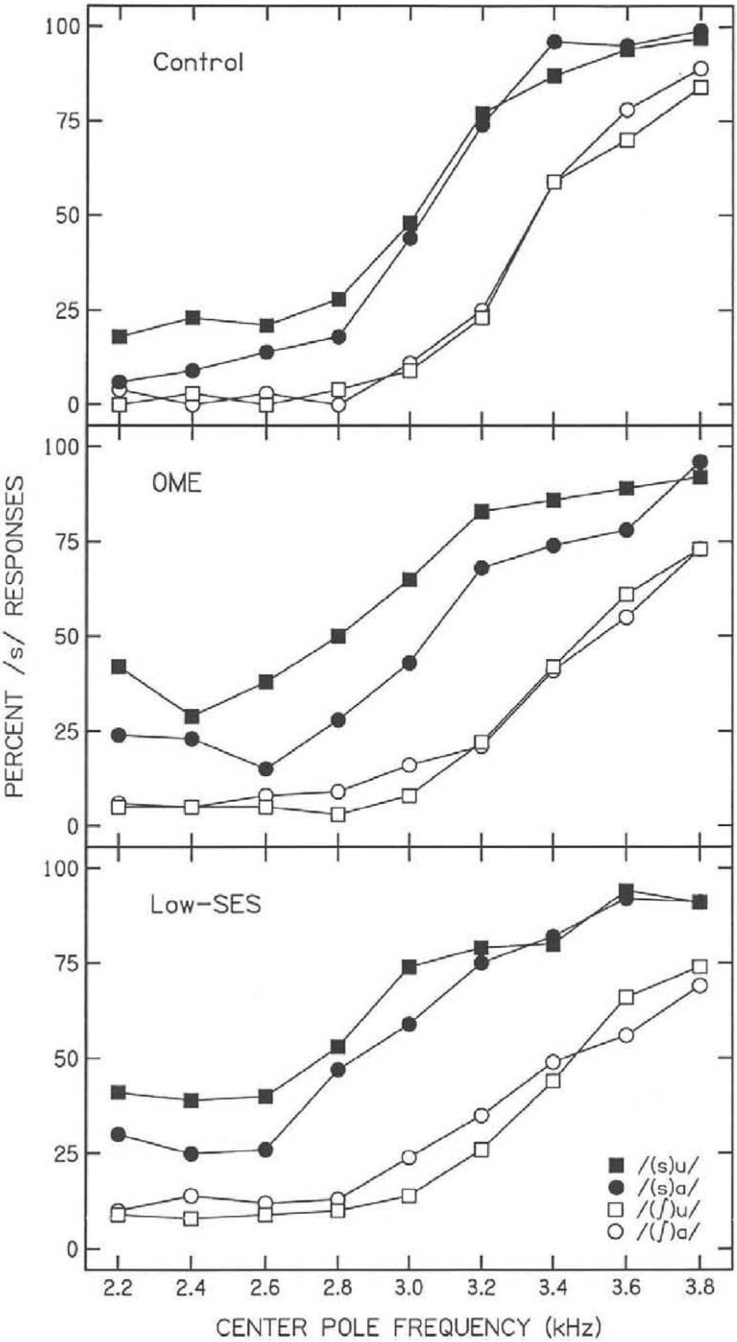

Fig. 1. Labeling functions for the fricative-vowel speech perception task.

Table 2
Mean slope (in probit units per kHz of fricative noise) for each age group, with standard deviations in parentheses

	Control	OME	Low-SES
/(ʃ)u/	2.57 (1.46)	1.56 (0.66)	1.60 (1.04)
/(ʃ)ɑ/	3.28 (1.18)	1.76 (0.53)	1.80 (1.18)
/(s)u/	3.77 (1.78)	2.08 (0.80)	1.94 (1.21)
/(s)ɑ/	3.72 (1.55)	1.76 (0.47)	1.47 (0.78)

The ‘s’ or ‘ʃ’ in parentheses at the left indicates the fricative for which formant transitions were appropriate.

Table 3
Mean separation in phoneme boundaries (in Hz) as a function of formant transitions for each age group, with standard deviations in parentheses

	Control	OME	Low-SES
/(ʃ)u/-/(s)u/	592 (314)	1005 (498)	1126 (506)
/(ʃ)ɑ/-/(s)ɑ/	438 (153)	635 (281)	808 (549)

Group means for slopes, for each syllable type, are shown in Table 2. Children in the *control* group had steeper functions than children in either of the other two groups.

From Fig. 1 it is clear that there were no differences in general placement of the labeling functions across listener groups. But the parameter of most interest (regarding placement) is the separation between functions (measured at phoneme boundaries) depending on whether formant transitions were appropriate for /ʃ/ or /s/. Table 3 shows mean separations between functions for stimuli with /ʃ/ and /s/ transitions, for /u/ and /ɑ/ separately. These separations were greater for children in the *OME* and *low-SES* groups than for children in the *control* group.

A series of ANOVAs and post hoc t tests, using Bonferroni adjustments, confirmed impressions from Fig. 1 and Tables 2 and 3. One-way ANOVAs, with group as the factor, were done on mean slopes across formant-transition conditions for the vowels /ɑ/ and /u/ separately. For /ɑ/ the main effect of group was found to be significant, $F(2, 31) = 13.77$, $P < 0.001$. The post hoc t tests revealed highly significant differences between the *control* and *OME* groups, $t(31) = 4.46$, $P < 0.001$, and between the *control* and *low-SES* groups, $t(31) = 4.56$, $P < 0.001$. Both of these effects are significant with Bonferroni adjustments at the 0.001 level. For /u/ the main effect of group was also found to be significant, $F(2, 31) = 6.54$, $P = 0.004$. The post hoc t tests again revealed significant differences between the *control* and *OME* groups, $t(31) = 3.31$, $P = 0.004$, and between the *control* and *low-SES* groups, $t(31) = 3.09$, $P = 0.004$. Both of these effects are significant with Bonferroni adjustments at the 0.001 level. No differences in slopes were found between the *OME* and *low-SES* groups.[2] We may conclude that children in the *control* group had steeper functions than children in either of the other two groups, and that this finding reflects a

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[2] Throughout this paper, exact results of any statistical test with a P of less than 0.10 will be reported. Therefore, if an exact F or t ratio is not given, it can be assumed that the value had an associated P of greater than 0.10.

greater weighting of the fricative-noise spectrum in labeling decisions by the control group. Children in the *OME* and *low-SES* groups had similar slopes, suggesting similar weights were assigned to the fricative noises.

ANOVAs were also done on the separations between functions for stimuli with /ʃ/ and with /s/ transitions. For /ɑ/ a marginal effect of group was found, $F(2,31) = 3.03$, $P = 0.063$. Likely the large variability exhibited by the *low-SES* group compared to the other two groups accounted for this effect not being stronger. Post hoc testing revealed a significant difference only between the *control* and the *low-SES* groups, $t(31) = -2.45$, $P = 0.020$, which is significant at a 0.01 level when Bonferroni adjustments are used. However, when a simple t test was done on differences for children in the *control* and *OME* groups, it was found to be significant, $t(22) = -2.13$, $P = 0.045$.[3] The ANOVA on group differences in transition effect for /u/ was significant, $F(2,31) = 4.51$, $P = 0.019$. The post hoc t tests were significant for comparisons between the *control* and *OME* groups, $t(31) = -2.28$, $P = 0.030$, and between the *control* and *low-SES* groups, $t(31) = -2.81$, $P = 0.009$. The first of these comparisons is significant at the 0.10 level when Bonferroni adjustments are used, and the second is significant at the 0.05 level. No differences in separation of functions were found for the *OME* versus *low-SES groups*. Overall it seems fair to conclude that children in the *OME* and *low-SES* groups weighted formant transitions more than children in the *control* group, a perceptual strategy that has been observed for younger children with no risk factors for language delays. Furthermore, children in the *OME* and *low-SES* groups showed similar results, suggesting that these conditions affect the development of perceptual strategies for speech similarly.

3.2.2. VOT

Only children in the *control* and *OME* groups participated in this task, and mean labeling functions are shown in Fig. 2. As expected, these functions appear similar for the two groups. Mean slopes across the two functions were 0.13 and 0.11 probit units per ms of change in VOT for the *control* and *OME* groups, respectively. This difference is not statistically significant. Mean phoneme boundaries for functions with /d/ and /t/ bursts are shown in Table 4, and seem to suggest that functions were separated a bit more for children in the *OME* group than for those in the *control* group. In fact, a t test done on these differences was significant, $t(23) = -2.37$, $P = 0.027$. It is difficult to attribute much importance to this finding, as there is only a 2-ms difference between the groups, and Nittrouer (1999) did not observe the effect for children with normal phonological processing abilities and those with poor phonological processing abilities. Clearly, however, children in the *OME* group did not have difficulty processing temporal information generally or brief cues specifically. If they had had trouble processing temporal information (or using brief cues), their phoneme boundaries would have been at longer

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[3] On those measures for which there are data from children in all four groups (or three of the four groups), t tests were also performed on only data from the children in the *control* and *OME* groups. Because children in these two groups provided data on all measures it seemed reasonable to treat results for these two groups across the set of measures somewhat as a discrete study. In this particular case (i.e., the transition effect for /ɑ/) this procedure seemed especially appropriate because of the large variability exhibited by children in the *low-SES* group. When results of these two-group t tests reveal something slightly different from what was found in the analyses for all groups, those results are reported.

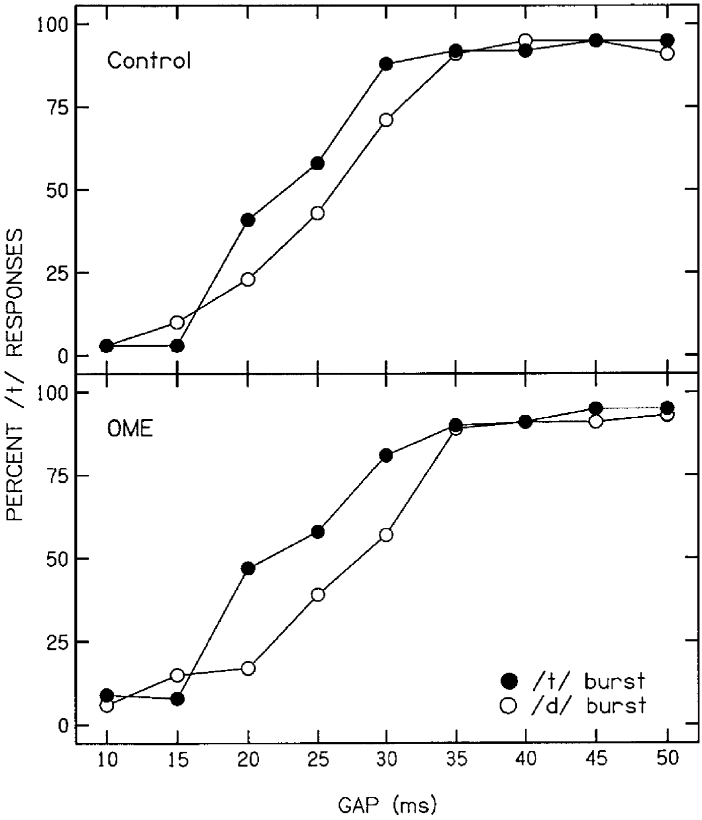

Fig. 2. Labeling functions for the VOT speech perception task.

VOTs (indicating that they needed longer gaps to recognize syllables as starting with the voiceless /t/) or their functions would have been less separated. These results suggest that the group differences observed for the fricative-vowel stimuli cannot be attributed to differences in abilities to perform the labeling task.

3.3. Phonological awareness

3.3.1. Syllable counting

All children participated in this task. Fig. 3 shows the mean number of words for which syllables were counted correctly, for each group. Children in all groups were able to do this

Table 4
Mean phoneme boundaries (in ms of VOT) for each age group, with standard deviations in parentheses

	Control	OME
/d/ burst	26.5 (3.9)	27.0 (5.2)
/t/ burst	24.4 (3.5)	22.9 (3.9)

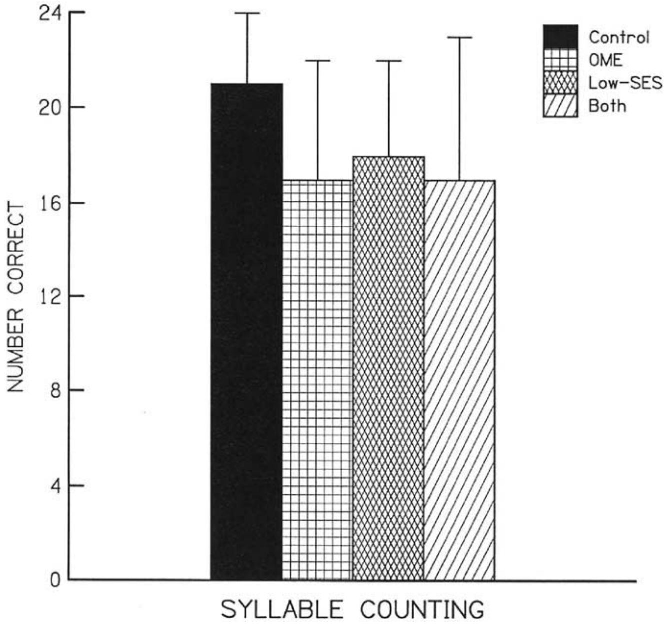

Fig. 3. Number of items correct for the syllable counting task.

task with a fair degree of accuracy: most children (two-thirds of them) got at least 0.67 of the items correct (i.e., more than 16 of the 24 items). The ANOVA done on these numbers did not reveal a significant effect of group, $F(3, 45) = 2.36$, $P = 0.084$. Consequently, it seems fair to conclude that children in all groups were capable of performing metalinguistic tasks, when they were aware of the linguistic structure being analyzed.

3.3.2. *Same-different ICTS*

All children participated in this task. Fig. 4 shows mean percentages of items judged correctly for each group. As can be seen, mean performance for the three experimental groups was not above chance. The ANOVA done on these data showed a significant group effect, $F(3, 45) = 4.11, P = 0.012$. Results of the post hoc *t* tests are shown in Table 5, and reveal significant comparisons for the *control* group versus each of the three experimental groups. Using Bonferroni adjustments, comparisons of the *control* group versus each of the *low-SES* and *both* groups are significant at the 0.05 level. Using Bonferroni adjustments, the comparison of the *control* versus *OME* groups did not reach the 0.10 level of significance, but the simple *t* test for just the *control* and *OME* groups was significant, $t(23) = 2.93$, $P = 0.008$. None of the post hoc comparisons between any pair of experimental groups resulted in statistical significance. In summary, children in the three experimental groups performed differently from children in the *control* group, but similarly to each other.

3.3.3. *Three-choice ICTS*

Only children in the *control* and *OME* groups participated in this task. Fig. 5 shows mean percentages of items judged correctly for each group. The *OME* group mean is not above

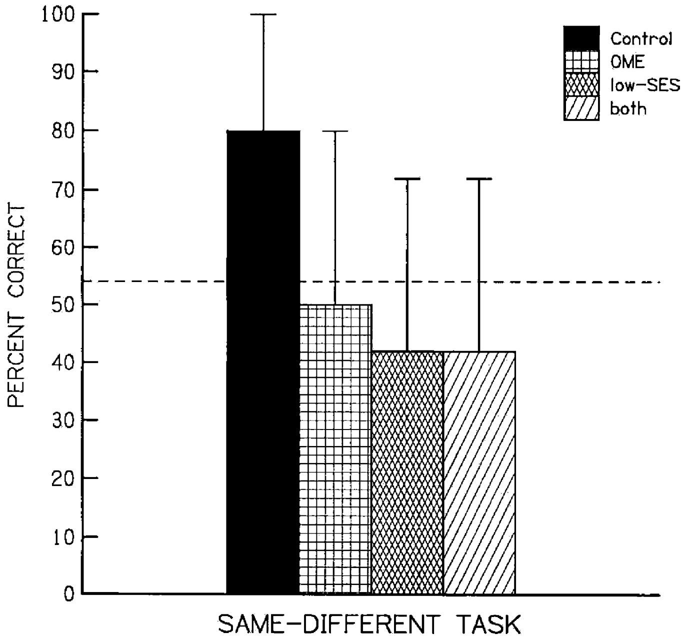

Fig. 4. Percentages of items correct for the same-different initial-consonant-the-same task. The dashed line shows the upper limit of chance performance.

chance, and a t test demonstrated that performance for the two groups differed significantly, $t(23) = 2.74$, $P = 0.012$.

3.4. Verbal working memory

Only children in the *control* and *OME* groups participated in this task. Table 6 shows the mean number of errors (collapsed across list positions) for rhyming and nonrhyming materials, for both the three- and four-item lists. ANOVAs were done on the mean number of errors across list positions for the three- and four-item lists separately, with group as the between-subjects factor and rhyme condition as the within-subjects factor.

Table 5
Results of post hoc t tests for the same-different ICTS task

	t	P
Control vs. OME	2.39	0.021
Control vs. low-SES	3.01	0.004
Control vs. both	3.04	0.004
OME vs. low-SES	0.68	0.502
OME vs. both	0.71	0.484
Low-SES vs. both	0.03	0.978

Degrees of freedom were 45.

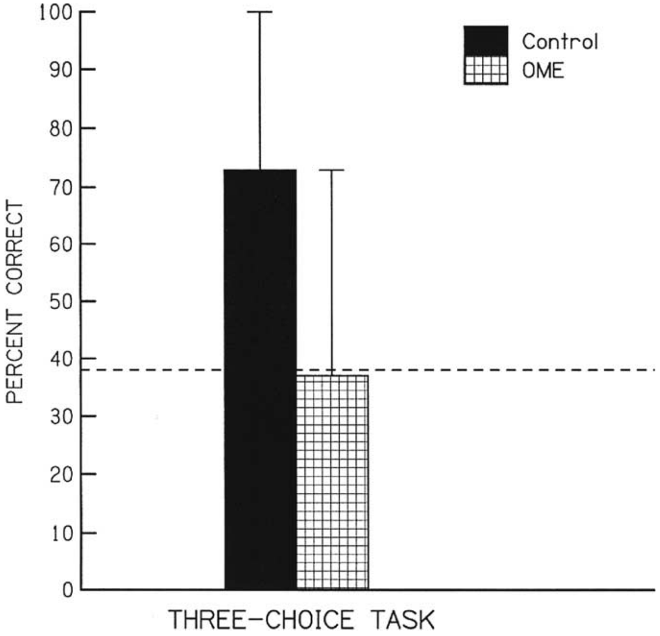

Fig. 5. Percentages of items correct for the three-choice initial-consonant-the-same task. The dashed line shows the upper limit of chance performance.

For the three-item lists very few errors were made overall, and so the distribution of errors was skewed. Consequently, the data were analyzed using arcsine transforms of mean proportions of errors. Results for the three-item lists revealed significant main effects of group, $F(1, 23) = 4.84$, $P = 0.038$, and rhyme condition, $F(1, 23) = 10.40$, $P = 0.004$. The interaction of group × rhyme condition was not significant. Errors for the four-item lists were not skewed, and so these data were analyzed without arcsine transforms. For these lists, the main effect of group was significant, $F(1, 23) = 5.90$, $P = 0.023$, as was the main effect of rhyme condition, $F(1, 23) = 29.32$, $P < 0.001$. Again, there was no significant interaction of group × rhyme condition. Overall, children in the *OME* group made more errors on this recall task than children in the *control* group.

Table 6
Mean errors across list positions (out of 10) for each age group on the verbal working memory task, with standard deviations in parentheses

	Control	OME
Three items		
Rhyming	0.78 (1.33)	1.77 (1.66)
Nonrhyming	0.42 (1.11)	1.10 (1.67)
Four items		
Rhyming	2.98 (2.31)	4.58 (2.44)
Nonrhyming	1.54 (1.66)	3.29 (2.75)

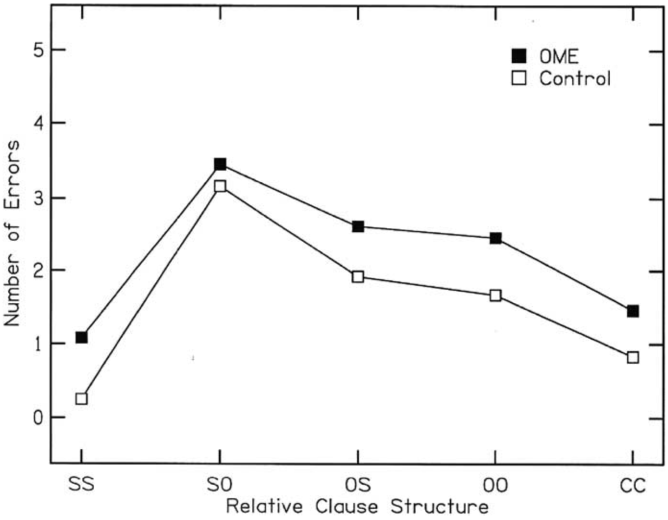

Fig. 6. Mean number of errors across sentence types for the sentence comprehension task. Labels on the x-axis indicate the type of relative clause structure. Both the 'S' (subject) and 'O' (object) refer to roles of the noun in the empty position of the relative clause. The first letter indicates its role in the main clause, and the second letter indicates its role in the relative clause. 'CC' refers to sentences with conjoined clauses.

3.5. Comprehension of sentences with complex syntax

Only children in the control and OME groups participated in this task. Mean numbers of errors are shown in Fig. 6. As can be seen, the pattern of errors across sentence types is similar for both groups, with the most errors being made to sentences in which the subject of the main clause is the object of the relative clause (e.g., The boy who the girl pushed hugged a teddy bear). An ANOVA was done on these data, with group as the between-subjects factor and sentence type as the within-subjects factor. Because overall error rates were low, arcsine transforms were used. The effect of group was marginally significant, $F(1, 23) = 4.12$, $P = 0.054$, and the effect of sentence type was highly significant, $F(4, 92) = 19.99$, $P < 0.001$. The interaction of group × sentence type was not significant. Mean number of errors across all sentence types was 1.6 for the *control* group (S.D. = 0.2), and 2.2 for the *OME* group (S.D. = 0.2). Again, children in the *OME* group made more errors overall than children in the *control* group.

3.6. Nonspeech temporal processing

Only children in the *control* and *OME* groups participated in this task. Three children in the *control* group and five children in the *OME* group did not reach the test phase of the procedure. All of these children were eliminated for the same reason: they were unable to remember the button associated with each tone after tones stopped being played when the buttons were pressed (i.e., at the third level of training). Thus, there were data from nine children in the *control* group and eight children in the *OME* group. Fig. 7 shows the mean

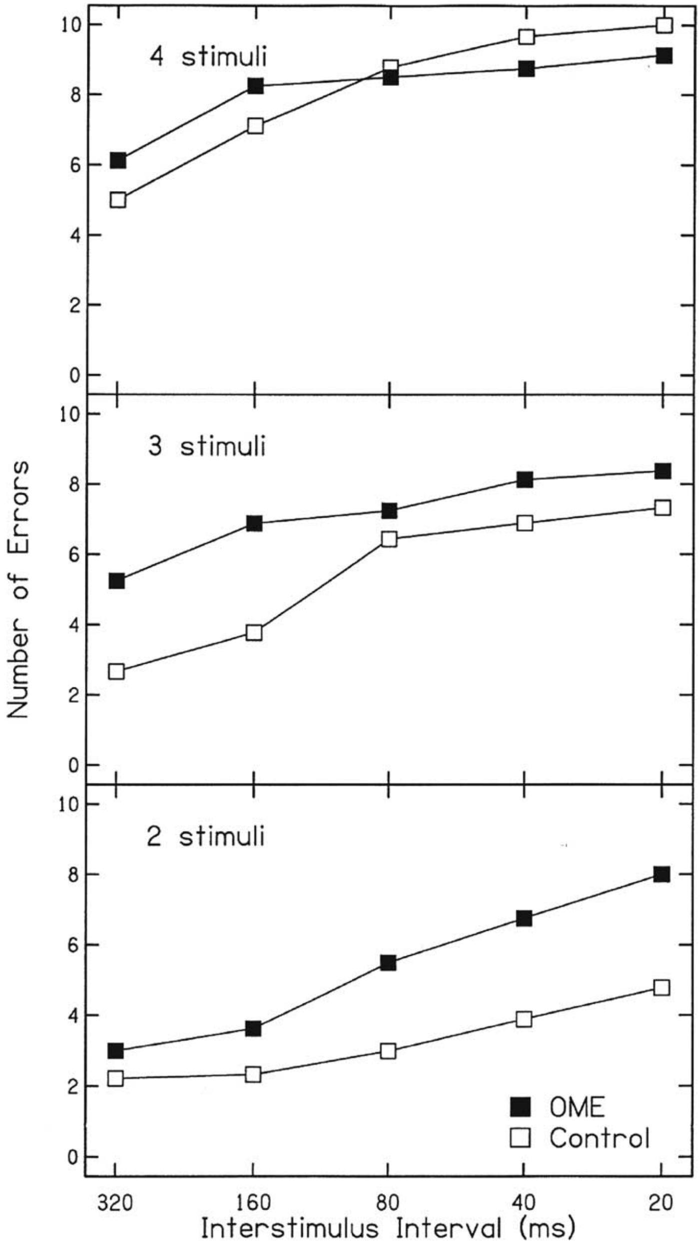

Fig. 7. Mean number of errors across ISIs for the temporal-processing task.

number of errors for each group across ISIs for the four-tone, three-tone, and two-tone sequences. If temporal-processing deficits accounted for any of the diminished language abilities demonstrated by children in the *OME* group, compared to children in the *control* group, we would expect to see children in the *OME* group making significantly more errors at short ISIs. We see this trend somewhat for the two-tone sequence (Fig. 7, bottom panel). For the three-tone sequence (Fig. 7, middle panel), we see a pattern exactly opposite to what would be predicted. The four-tone sequence shows no particular pattern across ISIs.

Two-way ANOVAs were performed on these data, with group as the between-subjects factor and ISI as the within-subjects factor, at each level of sequence length separately. The main effect of group was not significant at any sequence length, in spite of the fact that the mean numbers of errors are slightly higher for the *OME* group than for the *control* group across ISIs for the two-tone and three-tone sequences. The main effect of ISI was significant at every sequence length: two tones, $F(4, 60) = 19.90$, $P < 0.001$; three tones, $F(4, 60) = 28.50$, $P < 0.001$; and four tones, $F(4, 60) = 30.61$, $P < 0.001$. Of course the term of most interest is the group × ISI interaction because the prediction was that errors would increase as ISI decreased more for the *OME* group than for the *control* group, *if children in the OME group suffered from a temporal-processing deficit*. This interaction was close to significant for the two-tone sequence, $F(4, 60) = 2.19$, $P = 0.081$, and clearly significant for the three-tone sequence, $F(4, 60) = 2.80$, $P = 0.034$. To determine if these interaction effects reflected more errors for children in the OME group at brief ISIs a series of t tests were done, at each ISI, for each sequence length. Only one of these t tests showed a significant difference in the number of errors between the two groups: the three-tone sequence, 320-ms ISI, $t(15) = -2.28$, $P = 0.038$. However, this is the longest ISI and so this result did not fit the prediction. The t test for the two-tone sequence, 20-ms ISI, was close to significant, $t(15) = -1.84$, $P = 0.086$. Because only this sequence length (two tones) showed the pattern predicted by the hypothesis that temporal-processing deficits underlie language delays and/or disorders, and in fact one sequence length (three tones) showed exactly the opposite pattern to that prediction, we conclude that children in the *OME* group did not have more difficulty processing rapidly arriving signals than children in the control group: that is, children in the OME group did not have a temporal-processing deficit.

4. Discussion

This study was undertaken to test one specific hypothesis about the role of early experience with one's native language in the development of certain language abilities. The hypothesis was that early language experience facilitates the acquisition of the language-specific weighting strategies for speech perception that make the recovery of segmental structure most efficient. In turn, access to segmental structure facilitates the coding and retrieval of linguistic material in working memory that is required for comprehending sentences with complex syntactic structure. The results of this study support all components of this hypothesis: Children with histories of early, chronic OME or living in low-SES environments (conditions which are both presumed to diminish language experience) showed perceptual weighting strategies typical of younger children without such backgrounds and poorer abilities on tasks such as syllable and phoneme awareness than children experiencing neither chronic OME nor low-SES. Mid-SES children with histories of early, chronic OME also showed poorer serial recall of word lists and poorer comprehension of sentences with complex syntax than mid-SES children without those histories. Taken together these results support one suggestion about how deficits in early language experience can affect later language abilities: these deficits interfere with the learning of language-specific perceptual strategies for speech. Being delayed in the acquisition of appropriate strategies for speech perception are related to delays in gaining access to phonetic structure, and those delays appear to affect (negatively) the abilities of children to store and retrieve language in working memory. These abilities would be affected because access to phonetic structure is necessary for efficient storage and retrieval of words. If unable to store sufficiently long sequences of linguistic material in working memory, a child will have difficulty comprehending sentences with relative clauses.

The suggestion being made here (that deficits in early language experience can have their impact at the levels of speech perception and phonological processing) does not negate the possibility that deficits in early language experience can have a direct effect at the level of syntactic learning, as well. Using measures of expressive language, Huttenlocher (1998) found that the speech samples of children from mid-SES homes contained more than 25% complex utterances, while the samples of children from low-SES homes contained fewer than 10%. Correspondingly, caregivers of children from low-SES homes used far fewer complex sentences than caregivers in mid-SES homes. The current study looked at the processing and comprehension of sentences with complex structures. Results of children in the *control* and *OME* groups revealed no difference in knowledge about relative clauses: the pattern of errors across types of clauses was similar, a finding generally taken to support the position that the problem revealed by greater numbers of errors is one of processing, not of syntactic knowledge (e.g., Smith et al., 1989). Thus, it may be that OME, in the absence of low-SES, may give rise to processing deficits only, while low-SES may lead to both processing and syntactic lags.

It is not clear from these results whether the effects of low-SES and OME combined in some fashion. Half the children in the *both* group were unable to label even natural tokens of ‘‘Sue’’ and ‘‘shoe’’ correctly, as opposed to 17% of children in the *low-SES* group. However, it would be premature to conclude much from this result. No differences between the *low-SES* and *both* groups were found on the tests of phonological awareness, but on one of these (the same-different ICTS task) children in all three experimental groups performed at chance levels. Consequently, it is not possible to compare the effects of low-SES alone or in combination with histories of OME. Performance on the other phonological awareness task (syllable counting) was predicted to be fairly good for all these 5-year-olds, and so that task was included largely as a test of whether or not all children in the study could perform tasks requiring explicit demonstrations of their metalinguistic abilities. Thus, this study provides no new evidence regarding the question of whether the effects of OME and low-SES are additive or redundant for the set of language skills examined here. Nittrouer (1996b) concluded that these effects were redundant for older children, and results of this study do not conflict with that conclusion.

One theoretical suggestion that these results did not support is the idea that delays in language development are based on constraints in processing rapidly arriving signal portions (e.g., Merzenich et al., 1996; Tallal et al., 1996). In spite of demonstrating delays in the development of awareness of linguistic structure, verbal working memory, and comprehension of sentences with complex syntax, children in the *OME* group showed no special deficits recalling short tones presented at brief ISIs. This failure to find a temporal-processing deficit for children who showed delays for several kinds of language processing is in line with results of others demonstrating that nonlinguistic, auditory deficits are not associated with specific phonological problems (e.g., Nittrouer, 1999), general language problems (e.g., Bishop, Carlyon, Deeks, & Bishop, 1999), or reading problems (Mody, Studdert-Kennedy, & Brady, 1997; Rosen & Manganari, 2001). Furthermore, children in the *OME* group had no difficulty using brief signal portions in speech perception: In labeling stimuli that varied in VOT and noise bursts, children in the *OME* group did not require longer VOTs than children in the control group to hear stimuli as starting with a voiceless stop, and they used the 10-ms noise bursts even slightly more than children in the *control* group in their voicing decisions. This result serves to place the locus of the effects of early language experience clearly on linguistic abilities, rather than on general auditory abilities. Thus, one clinical implication of this study is that intervention for children at-risk for delays in language development should focus on linguistic abilities using language-related activities, rather than on tasks using nonspeech auditory signals.

At first glance the finding that 5-year-olds from mid-SES backgrounds with histories of early, chronic OME exhibited delays in speech perception, phonological processing, and comprehension of sentences with complex syntax might appear to conflict with conclusions of others that OME poses no risk to language development. In particular, two groups of investigators reached this conclusion based on data from large prospective studies: Roberts and colleagues (e.g., Roberts, Burchinal, & Zeisel, 2002) and Paradise and colleagues (e.g., Paradise et al., 2001). However, that work needs to be considered in the context of methods used. In most reports from these groups parental checklists such as the MacCarthy Scales (McCarthy, 1972) and/or standardized tests such as the Clinical Evaluation of Language Fundamentals (CELF) (Semel, Wiig, & Secord, 1995) were used as dependent measures. While such tools serve as adequate screening measures they generally do not provide in-depth assessments of children's abilities in specific domains. Parental checklists can never provide evaluations of deep language processing because parents are not able to evaluate language processing at that level. Regarding the use of standardized tests, Briscoe et al. (2001) showed that children with risk factors for language delays can perform within normal limits on such tests, yet still demonstrate delays on measures of phonological awareness and processing. Delays in these latter skills predict problems for children in their academic lives that can be missed by standardized tests. For example, Brady et al. (1983) showed that children with phonological processing problems have more difficulty in understanding speech in noise than children without these problems, and classrooms are notoriously noisy. Nittrouer and Miller (1999), as well as this study, showed that phonological processing problems are associated with more errors on recall of word lists and in comprehending sentences with complex syntax, and so children with such problems could have difficulty in retaining sequences of several directions, as frequently given in classroom settings. We might also predict that children with phonological processing problems would be slower at processing language than children without these problems, and several studies report that children with specific language impairments demonstrate slower processing times than children without such impairments (e.g., Fazio, 1998; Miller, Kail, Leonard, & Tomblin, 2001). Although questions remain about the precise nature and underlying basis of this deficit (e.g., Lahey, Edwards, & Munson, 2001), it is reasonable to suspect that children with the sorts of difficulties exhibited by the children in the *OME* group here might encounter some difficulty keeping up with class discussions.

Another problem with the studies of Roberts and colleagues and Paradise and colleagues is that the majority of children in both their OME and non-OME groups came from low-SES backgrounds. Often their participants with histories of OME performed at the low end of normal on standardized language measures, but these scores were not found to be statistically different from participants in their studies with negative OME histories. Likely that is because there was never any group of mid-SES children with no OME histories to which to compare these scores. As in the present study, children in such control groups often score several points higher than the population mean of 100. Consequently, statistically significant differences can be obtained for these control and experimental groups, even though both may be within ±1S.D. of the population mean. For example, the most recent report from Roberts and colleagues (Roberts et al., 2002) provides test scores for second graders from predominantly low-SES environments. Although largely a correlational analysis of OME history and test scores, it is reported that mean scores for both receptive and expressive language on the CELF were 92.9. This is certainly lower than we would expect for mid-SES children with no histories of chronic OME, and lower than scores observed for such children in this study on the one standardized language measure obtained for screening (PPVT-III).

Paradise and colleagues have published several reports from the same group of children with OME histories (e.g., Paradise et al., 2001), comparing outcomes based on whether the children were randomly assigned to receive ventilation tubes "early" (i.e., soon after meeting criteria to participate in the clinical trial) or "late" (6 months later for bilateral effusion and 9 months later for unilateral effusion). However, an important shortcoming of this design must be noted: Although children in these studies were assigned to "early" or "late" treatment groups, there was overlap between the two groups in when ventilation tubes were actually placed. Reasons for this overlap included factors such as delays in obtaining approval to insert tubes from insurance providers for children in the early treatment group and parental insistence on immediate tube placement for children in the late treatment group. Nonetheless, children were categorized for analysis purposes based only on when their parents were told to get treatment. Furthermore, children in both groups were predominantly from low-SES homes. Given these confounds it is not surprising that no differences on dependent measures were found for the two groups, but results for both groups were lower than what would be expected for children from mid-SES homes with no histories of chronic OME.

A report from this same group of investigators provides the appropriate comparison scores. Dollaghan et al. (1999) used the same measures as Paradise et al. (2001) to compare outcomes for several groups of 3-year-olds who differed in maternal education, a correlate of SES. Table 7 shows results of Dollaghan et al. and of Paradise et al. for mean length of utterance (MLU), number of different words (NDW), and PPVT-R. For results of Dollaghan et al., means given under the heading 'mid-SES' are for children

Table 7
Mean scores for each of four groups of 3-year-olds from Dollaghan et al. (1999) and Paradise et al. (2001), on the PPVT-R, mean length of utterance (MLU), and number of different words (NDW)

	Dollaghan et al. (1999)		Paradise et al. (2001)	
	Mid-SES	Low-SES	Early treatment	Late treatment
PPVT-R	110 (14)	90 (18)	92 (13)	92 (15)
MLU	3.3 (0.7)	2.7 (0.8)	2.7 (0.7)	2.8 (0.7)
NDW	143 (28)	118 (36)	124 (32)	126 (30)

Standard deviations are given in parentheses. Data from the Dollaghan et al. report comes from their Table 3, and data from the Paradise report comes from their Table 4.

whose mothers had completed college and means given under the heading 'low-SES' are for children whose mothers had not completed high school. In the Paradise study, 50% of the children had mothers who had not gone beyond high school in their education, and only 8% had mothers who had attended college. In the Dollaghan study, 75% of the children categorized as 'low-SES' were on Medicaid, a good indicator that annual family income is low. In the Paradise study, 64 and 65% of children in the early and late treatment groups, respectively, were on Medicaid. As can be concluded from Table 7, 3-year-olds in both the early and late treatment groups of Paradise et al. performed similarly to 3-year-olds in the low-SES group of Dollaghan et al. In general, results of Roberts and colleagues and of Paradise and colleagues are consistent with results of Nittrouer (1996b) and the present study suggesting that the effects of early, chronic OME are redundant to the effects of low-SES. Because of the several confounds in the studies of Roberts and colleagues and Paradise and colleagues, they fail to provide compelling evidence that early, chronic OME poses no risk to language development.

In summary, the current study extends our understanding of what it means to say that a child learns language through hearing. Speaker/listeners of different languages make use of different perceptual strategies to derive phonetic structure from the acoustic signal: These strategies emerge for the young child only through extensive listening (and probably speaking) experience. If the acquisition of language-appropriate perceptual strategies is delayed, the child will be delayed in learning to recognize phonetic structure efficiently, and so will have more difficulty storing and retrieving words in working memory. Even the ability to comprehend sentences with complex syntax will suffer. The finding that children with different risk factors show similar delays strengthens these suggestions about the role of language experience.

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Appendix A. Educational and occupational indices for socio-economic status

Educational index
1.0 = completed elementary school
2.0 = completed junior high
2.5 = received general education degree
3.0 = completed high school
3.5 = completed 1 or more years of technical/vocational school
4.0 = completed technical/vocational school
5.0 = completed 1 or more years of university/college
6.0 = bachelor's degree
6.5 = completed 1 or more years of graduate school
7.0 = master's degree
7.5 = course work completed for Ph.D., but no dissertation; law degree without bar; medical degree without internship completed
8.0 = Ph.D.; law degree with bar; medical degree with internship completed

Occupational index
1 = maid, parking lot attendant, cafeteria worker, welfare recipient
2 = fast food worker, meter reader, housekeeper, delivery man, garbage man, packer, housewife, bill collector, telemarketer, waiter/waitress (e.g., bars), butler, factory worker, taxi driver, telephone operator, assembly line worker, data entry, nanny, bartender, painter (e.g., house), dishwasher
3 = daycare worker, construction worker, dispatcher, home appliance repairman, truck driver, bus driver, print room operator, gardener, machine operator, roofer, sales clerk, waiter/waitress (higher), brewer, camp counselor, dry cleaner, butcher, chef at a diner, exterminator, telephone company technician, mailman, car salesman, retail sales, military enlisted, post office clerks, welder, auto body repairman, bank teller/clerk, engraver, mechanic, beautician, service technician, janitor, carpet installer, brick mason, security guard, maintenance worker
4 = barber, travel agent, proofreader, baker, plumber, insurance agent, farmer, florist, sales representative, court reporter, fast food manager, electrician, tailor, locksmith, jeweler, bookkeeper, undergraduate student, carpenter, corrections officer, piano teacher, loan officer, factory supervisor
5 = advertising agent, actor/actress, construction foreman, librarian, interior decorating, real estate broker, missionary, funeral director, artist, laboratory technician, chef at a good restaurant, insurance adjustor, manufacturer, oral hygienist, musician, tavern owner, electrical contractor, L.P.N., public relations, social worker, executive assistant, office manager, radio/TV announcer, store manager (chain), executive secretary, personnel manager, accountant, contractor, graduate student, mortician, policeman, postmaster, fireman, medical technician, bank manager, firefighter
6 = computer programmer, restaurant owner, store or small business owner, elementary school teacher, research assistant, book or magazine editor, optician, real estate developer, stock broker, high school teacher, military captain/lieutenant, chiropractor,

Appendix A. (*Continued*)

registered nurse, military officer, lawyer, sheriff/police chief, clergyman, pharmacist, family therapist

7 = mayor, symphony conductor, engineer, large business owner, school principal, architect, judge, psychologist, veterinarian, company president, university professor, dentist

8 = university president, scientist, physician, surgeon

Appendix B. Items from the same-different initial-consonant-the-same (ICTS) task

Practice items			
1. Bark	Barn*	4. Pet	Pack*
2. Jump	Shirt	5. Blue	Bag*
3. Mat	Cap	6. Star	Clown
Test items			
1. Leap	Lip*	25. Peel	Pat*
2. Key	Kite*	26. Tile	Mask
3. Crumb	Drip	27. Note	Wheel
4. Date	Bag	28. Meat	Lace
5. Gate	Gum*	29. Soap	Salt*
6. Sky	Sleep*	30. Day	Box
7. Grape	Glue*	31. Wash	Vine
8. King	Dime	32. Zip	Zoo*
9. Dark	Pet	33. Stick	Slide*
10. Toes	Tip*	34. Plum	Price*
11. Class	Swing	35. Win	Well*
12. Web	Man	36. Pear	Pen*
13. Tree	Star	37. Soup	Light
14. Milk	Moon*	38. Frog	Brush
15. Pin	Boat	39. Fist	Sap
16. Claw	Crib*	40. Met	Map*
17. Lock	Pail	41. House	Heel*
18. Bit	Girl	42. Leg	Lock*
19. Foot	Pan	43. Prize	Stair
20. Drum	Flag	44. Rain	Kid
21. Bone	Bud*	45. Sled	Stick*
22. Fun	Fan*	46. Sun	Bin
23. Rug	Rag*	47. Jeep	Jug*
24. Can	Pit	48. Duck	Door*

Asterisks indicate the pairs that are the ‘same.’

Appendix C. Continuing education

1. Perceptual strategies for speech differ across languages because:
   a. Auditory capacities vary across groups of individuals.
   b. The acoustic properties that are important for recovering phonetic structure vary across languages.
   c. Alphabets differ across languages.
   d. The transmission of the various components of the speech spectrum differ depending on average temperature and altitude of a region.
   e. All of the above.
2. Many psycholinguists believe that in order to store words in verbal working memory a person must be able to access:
   a. Phonetic structure.
   b. The semantic categories of the words to be stored.
   c. Precategorical acoustic information.
   d. The orthographic symbols involved in writing the words.
   e. None of the above.
3. Children acquire the ability to recover phonetic structure from the acoustic speech stream by:
   a. Learning to extract phonemes one at a time, in sequential order.
   b. They are born being able to do so.
   c. Participating in a phonics approach to literacy instruction.
   d. Honing their speech perception strategies so that they attend to those acoustic properties that are most informative in their native language.
   e. All of the above, except c.
4. Some populations of children whom we would expect to be delayed in language development because of deficits in linguistic experience include:
   a. Children with hearing loss.
   b. Children with developmental delays.
   c. Children living in low-socioeconomic conditions.
   d. Children experiencing chronic episodes of otitis media with effusion during the first few years of life.
   e. All of the above, except b.
5. Results of this study suggest that intervention for children with language delays should focus on:
   a. Providing speech input that is initially slowed, and then gradually speeding up the rate of presentation.
   b. Providing speech that is in units of typical length, such as sentences, in natural contexts.
   c. Teaching children to focus on the phonemes that are easiest for them to hear first, like syllable-initial stops, and then moving to harder phonemes, like fricatives.
   d. Explicitly teaching phonological awareness skills, in increasing order of difficulty.
   e. All of the above.

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